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TECHNICAL REPORT

MATERIAL LABORATORY

NEW YORK NAVAL SHIPYARD
BROOKLYN 1, NEW YORK

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RESEARCH REPORT
on
A MOLDED SKIN SIMULANT MATERIAL WITH THERMAL AND OPTICAL CONSTANTS APPROXIMATING THOSE OF HUMAN SKIN

Lab. Project 5046-3, Part 105
Final Report
NS 081-001

Technical Objective AW-7
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ADMINISTRATIVE INFORMATION

1. This investigation is part of the general Thermal Radiation Program originally proposed by COMNYKNAVSHIPYD conf ltr S99/L5, Ser 960-92, of 15 Mar 1950 and formally approved by BUSHIPS restr spdltr S99-(0)(348), Ser 348-75, of 6 Apr 1950. The general Thermal Radiation program is under the supervision of the Armed Forces Special Weapons Project.

2. The Naval Material Laboratory (NML) was charged with the development of a physical method for evaluating protection afforded by clothing under intense radiation at a meeting at AFSWP on 24 June 1952. The request for this development was formalized by AFSWP conf ltr SWPTR 000.9 of 28 August 1952. At the conference of 24 June 1952 arrangements were made for the cooperation of the Atomic Energy Project, University of Rochester School of Medicine and Surgery, to obtain burn data for use in the development of the skin simulant by the Naval Material Laboratory.

ACKNOWLEDGMENT

3. The thermal radiation research and development program is under the direction of T. I. Monahan, supervisor of the Optics Section of the Naval Material Laboratory. The development of the NML BS SKIN SIMULANT for use in the study of burns behind fabrics was achieved through the combined efforts of the personnel of the Thermal Radiation Physics Unit and the Thermal Radiation Materials Unit, headed, respectively, by W. L. Derksen and R. C. Maggio. T. D. Murtha, Guy P. DeLhery and T. B. Gilhooley performed the validation experiments and computations.

INTRODUCTION

4. A discussion of the NML skin simulant program and the associated theoretical considerations have been presented in previous Laboratory reports[1,2]. In NML's early search for an adequate skin substitute, organic tissue (meat) was employed in conjunction with certain fabric studies on the protection afforded by heat-treated Orlon.[3] The inherent disadvantages of meat tissue are its poor handling qualities and unknown variations of physical properties with storage time. These deficiencies were overcome through the adoption of black polyethylene, an organic thermoplastic material, as a skin simulant.[4] Although the polyethylene was modified with a coating[4] to match more closely the optical constants of skin and proved satisfactory in many applications, it was deemed desirable to have a substance whose optical and thermal constants match as closely as possible those of skin. To obtain a higher density and conductivity than those of polyethylene, metal fillers were incorporated into phenol, urea and melamine formaldehyde types of molding resins. Various mixtures were made which gave the proper thermal response. However, the copper and zinc fillers rendered the substance opaque and unlike skin optically. Inorganic fillers such as quartz, talc, kaolin, zinc oxide and silica, were substituted for the metal filler. Each of these fillers was combined with various weight percentages of each of the formaldehyde condensation-type molding materials. Although several filler-resin mixtures were made having thermal properties similar to those of skin, the silica-urea formaldehyde (40-60 composition) was selected as the one which satisfied most of the required physical constants and other properties.

1, 2, 3, 4 Bibliography

PHYSICAL CHARACTERISTICS OF AN IDEAL SKIN SIMULANT

5. A material to replace skin as a cloth backing in thermal radiation burn studies must have, in addition to thermal and optical constants comparable to those of average human skin, good resistance to thermal shock and heat. Volatile products resulting from the degradation of cloths and deposited on the backing must be easily removed. The material, therefore, must be unaffected by chemical solvents and moisture. Machinability is desirable to facilitate the drilling and tapping necessary for the mounting of contact terminals for attaching thermocouples. Molded pieces have been cut and the internal surfaces highly polished to obtain smooth faces against which are placed thermally sensitive indicating papers. For use in field exposures, the material should withstand blast and mechanical shock and be sufficiently hard to resist penetration of dust and other blast driven particles. The basic ingredients or molding materials must be readily obtainable and of known purity and composition and be adaptable to the usual laboratory mixing, grinding and molding operations. The NML BS skin simulant satisfies all of the above requirements and can be easily reproduced by other laboratories and commercial molders.

FABRICATION OF NML BS SKIN SIMULANT

6. The basic molding materials and equipment used in the fabrication of the skin simulant are described in Table 1. For a 20 gram specimen, 12 grams of resin and 8 grams of silica filler are required. A batch of 4 ounces in a quart jar is mixed and ball-milled for approximately one hour. This is sufficient material to make five 20-gram pieces, each measuring 3.8 cm in diameter and approximately 1 cm thick. The weighed mixture (20 grams) is placed in a preheated (275-290° F) press and molded at this temperature for 10-15 minutes under a pressure of 3500 to 4200 psi. The pressure is maintained until the press cools to about 100 F. The total time from charging to removal is about 30-40 minutes. The molding equipment used consists of a semi-automatic metallurgical specimen mounting press with 1-1/2" diameter standard mold dies. Additional dies made in the Material Laboratory are shown in Figure 1. Premolds, using a 1-1/4" mold assembly and a cold press, have been used as the charge for molding inserts and standard screw threads to which may be added binding posts for thermocouple mounting. The molded specimens, although hard and abrasive to tools, have, with care, been cut, drilled, tapped and sanded to a glossy finish.

PROOF-TESTING OF NML BS SKIN SIMULANT

7. In order to validate the physical skin simulant it was necessary to compare its thermal and optical constants with those of skin under identical exposure conditions. The equations of Buettner[5] were used to calculate the kpc product (specific thermal conductivity x density x specific heat) of skin and the simulant from the temperature rise maximum at the surface as indicated by a fine wire thermocouple. Buettner's expression for this product is

$$kpc = \frac{4AI^2\tau}{\pi(\Delta\theta)^2},$$

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k = specific thermal conductivity in $\left(\frac{\text{gm cal}}{\text{cm sec °C}}\right)$

p = density in $\left(\frac{\text{gm}}{\text{cm}^3}\right)$

c = thermal capacity in $\left(\frac{\text{gm cal}}{\text{gm °C}}\right)$

A = absorptivity -

I = intensity of incident radiation in $\left(\frac{\text{gm cal}}{\text{sec cm}^2}\right)$

τ = time of exposure in (sec)

$\Delta\theta$ = maximum temperature rise in (°C)

The Kpc product for human skin and the optical constants have been determined earlier by Hardy and NML.[6,7,8] The Kpc values for skin and other material compositions are listed in Table 2. The Buettner equation holds for non-penetrating radiation. The NML uses a graphitic blackening agent with an absorptance (A) of 0.955.

8. A second method used to validate the physical simulant was to compare the temperature-time histories of skin and the simulant obtained by exposures of each medium behind an opaque cloth, using a fine-wire thermocouple on the surface of the simulant. Typical temperature-time history curves for four situations, blackened skin and blackened simulant, uncovered and cloth in contact, are presented in Figure 2.

APPLICATIONS OF NML BS SKIN SIMULANT

9. Although emphasis is placed on the simulant's use as a sub-fabric burn indicator in protection studies, the thermoset skin simulant may also be employed in investigations to determine the interrelation of environmental, source and material parameters associated with insults of radiant thermal energy on organic materials. As a backing, for heat-reflecting fabrics, rubberized cloths, flameproofed materials and special coatings, the simulant with its integrated thermocouple may be used to determine the thermal absorption and combustion characteristics of these materials. The skin simulant may be used in conjunction with thermal indicator papers placed within the simulant block, in field studies, eliminating the need of active instrumentation.

Approved:

A. B. JONES, Jr., CAPTAIN, USN
The Director

6, 7, 8 Bibliography

BIBLIOGRAPHY

1. Naval Material Laboratory. Research Report on the Use of Polyethylene as a Physical Measuring System for Evaluating Physiological Burns Behind Fabrics. Lab. Project 5046-3, Part 42, November 1954. AD-51 869

2. Naval Material Laboratory. Research Report on a Review of the Development of a Plastic Physical Skin Simulant for Evaluating Sub-Fabric Flash Burns. Lab. Project 5046-3, Part 84, July 1955. AD-76 914

3. Naval Material Laboratory. Research Report on the Relative Protection Against Radiation Burns Provided By Heat-Treated Orlon. Lab. Project 5046-3, Part 20, Aug. 1952.

4. Naval Material Laboratory. Research Report on a Review of the Development of a Plastic Physical Skin Simulant for Evaluating Sub-Fabric Flash Burns. Lab. Project 5046-3, Part 84, July 1955.

5. Buettner, K.: Effects of Extreme Heat and Cold on Human Skin, Analysis of Temperature Changes Caused by Different Kinds of Heat Application, J. Appl. Physiol. 3: 691-704, 1951.

6. Hardy, J. D. Summary Review of the Influence of Thermal Radiation on Human Skin, U. S. Naval Air Development Center Report No. NADC-MA-5415, November 1954.

7. Hardy, J. D. Measurements of Some Thermal Properties of Human Tissues. U. S. Naval Air Development Center, Report No. NADC-MA-5405, April 1954.

8. Naval Material Laboratory Research Report on The Thermal Conductivity and Diathermancy of Human Skin For Flash Burn Studies. Lab. Project 5046-3, Part 81, August 1955. AD 72 955

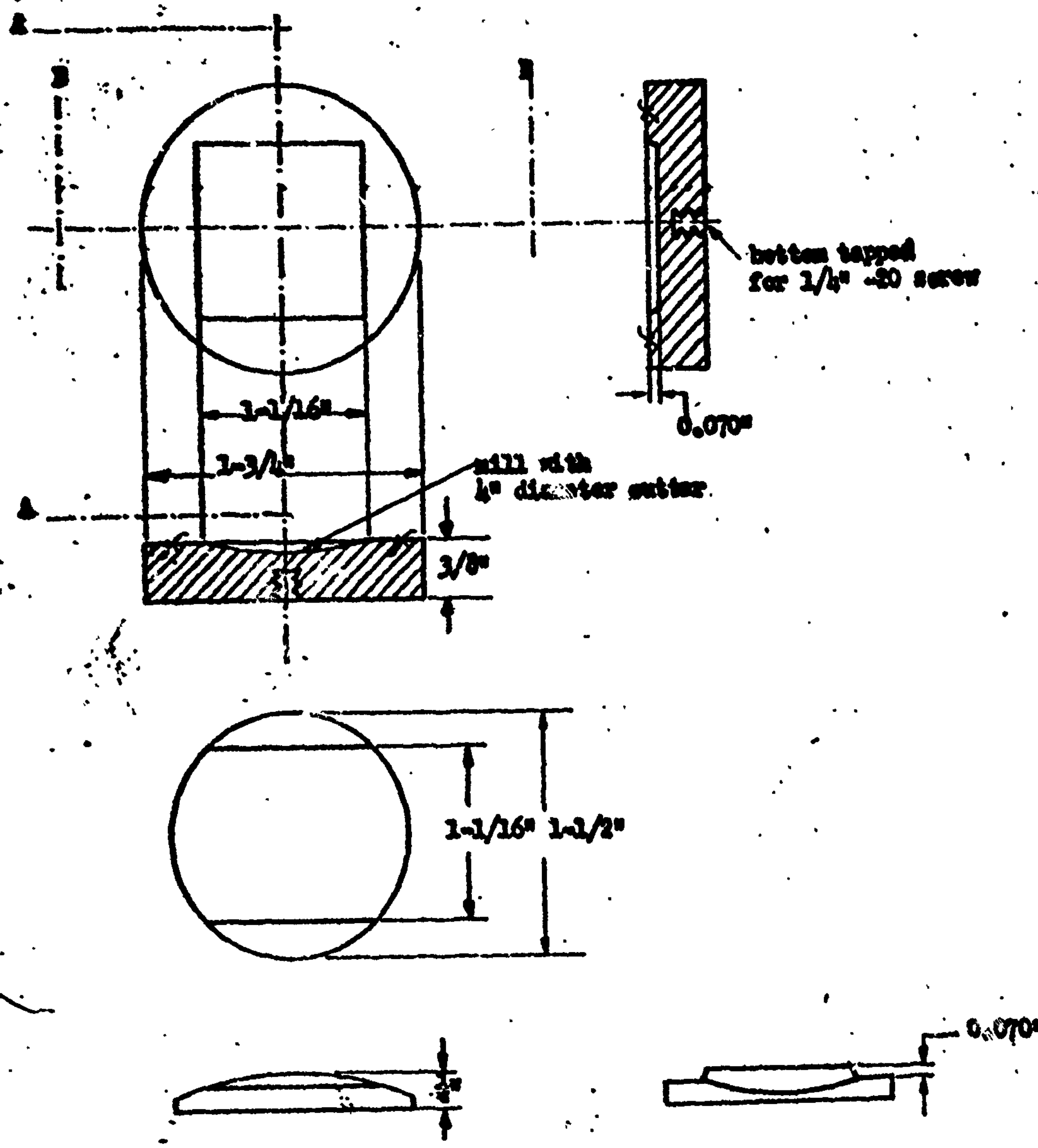

Fig. 1 - Dies for Molding Naval Material Laboratory Beetle-Silica Skin Simulant

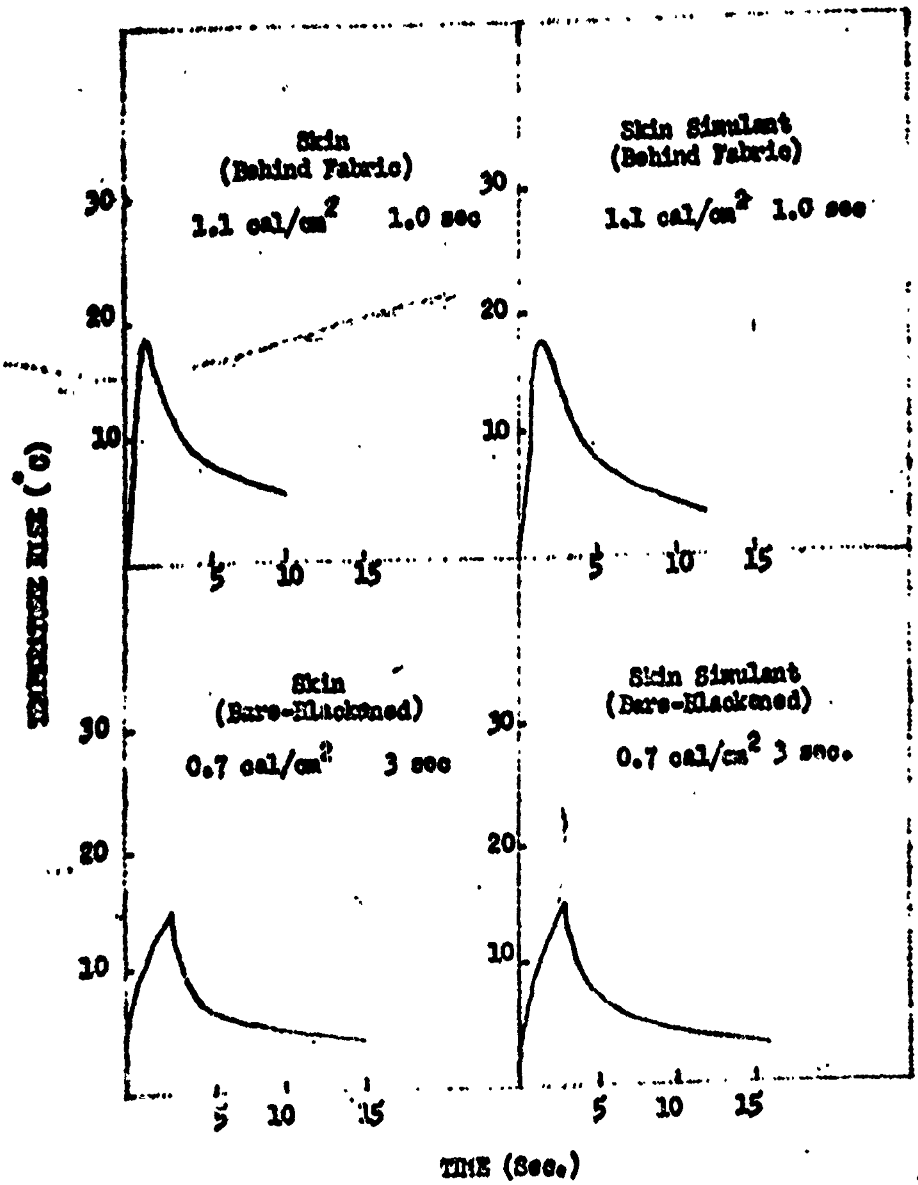

Fig. 2 - Temperature - Time Histories of Skin and NIL BS Skin Simulant

TABLE I

MOLDING MATERIALS AND EQUIPMENT USED IN MANUFACTURE OF
NML BS SKIN SIMULANT

Beetle* Molding Resin	
Color	MUP 32 Ivory
Flow	Very Soft
Batch	LK-299
Type	Powder
Supplier	American Cyanamid Co.
Silica	
Chemical Formula	SiO_2
Formula Weight	60.06
Type	Floated Powder
Mesh	About 240
Cat. No.	S-153
Lot No.	751126
Supplier	Fisher Scientific Co.

* Registered Trade Name of American Cyanamid's Alpha Cellulose Urea Formaldehyde Molding Resin.

Press	
Type	Semi-automatic Compression Molding
Mold Sizes	1-1/2" and 1-1/4" assemblies
Name	AB SPEED PRESS No. 1330
Supplier	Buehler Ltd., Evanston, Ill.
Thermocouple	
Type	Cupron
Wire Diameter (before copper plating)	.002"
(after copper plating)	.003"
EMF Constant	27 C/MV.
Supplier	Wilbur B. Driver Co.

TABLE 2

THE KpC OF SELECTED MATERIAL COMPOSITIONS EMPLOYED IN
NML SKIN SIMULANT DEVELOPMENT

Resin	Per cent (By wt.)	Filler	Per cent (By wt.)	KPc (cgs) $\times 10^{-4}$	ρ (gm/cm^3)	Molding Data: Pressure (PSI)	Molding Data: Temp. (°F)	Molding Data: Time (min.)
Polyethylene[1]	100	Carbon Black	1	4	1.0	--	--	--
Bakelite[2]	100		--	9.1	1.93	4000	220	2
Melmac 404[3]	100	--	--	4.2	1.47	4000	305	10
Melmac 404	75	Copper Dust	25	7.8	1.82	4000	225	10
Melmac 1077	100	--	--	5.8	1.47	4000	300	10
Beetle C-509[4]	100	--	--	5.8	1.40	4000	340	10
Beetle C-509	75	Quartz Powder	25	8.5	1.60	4000	230	10
Beetle C-509	75	Bakelite	25	7.5	1.53	4000	220	10
Beetle C-509	75	Copper Dust	25	9	1.96	3-4000	250	8
Beetle MUP-32	100	--	--	5.3	1.46	4000	270	10
Beetle MUP-32	75	Silica Floated Powder	25	6.3	1.65	4000	270	10
Beetle MUP-32	60	Silica Floated Powder	40	8.5	1.82	4000	270	10
Beetle MUP-32	50	Zinc Oxide	50	8	2.35	3-4000	225	8
Beetle MUP-32	50	(Quartz Powder (Zinc Oxide	25) 25)	9	2.18	3-4000	225	8
Human Skin		--	--	9[5]	--	Hardy[5]		--
Human Skin		--	--	8.6[5]	--	Naval Material Lab.[6]		

(1) E. I. dupont de Nemours & Co., Inc., Wilmington, Del.
(2) Trade name for phenol-formaldehyde molding compounds mfg. by Bakelite Co., New York, N. Y.
(3) Trade name for melamine-formaldehyde molding compounds mfg. by American Cyanamid Co., New York, N. Y.
(4) Trade name for urea-formaldehyde molding compounds mfg. by American Cyanamid Co., New York, N. Y.